FOREST PRODUCTS LABORATORY
RESIN-TREATED, LAMINATED, COMPRESSED WOOD
(COMPREG)

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FOREST PRODUCTS LABORATORY RESIN-TREATED LAMINATED, COMPRESSED WOOD (COMPREG)[1]

By

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Compressibility

A previous report in this series, (mimeograph 1380, entitled "Forest Products Laboratory Resin-Treated Wood (Impreg)" described the most effective treatment thus far tested by the Forest Products Laboratory for permanently reducing the swelling and shrinking of wood. It consists of the formation within the cell-wall structure of a phenol-formaldehyde resin after the wood has been treated with an aqueous solution of a completely water-soluble, virtually unpolymerized phenol-formaldehyde mix.

The treatment imparts a number of other important properties to the wood. One of these, not discussed in the previous report, is the wood's plasticity at polymerization temperatures, prior to the setting of the resin. Because of this plasticizing action of the resin-forming constituents, the wood can be compressed under considerably lower pressures than dry untreated wood.

For example, treated spruce, cottonwood, and aspen veneer dried to a moisture content of about 6 percent under the conditions described in mimeograph 1380 but not cured, will compress when subjected to a pressure of only 250 pounds per square inch at 300° F. to about half the original thickness and a specific gravity of about 1. A few preliminary tests indicate that redwood will compress to about the same degree under a pressure of only 200 pounds per square inch. The dry untreated veneers in contrast will compress only 5 to 10 percent under the same conditions. Resin-treated sweet, black, and tupelo gum and yellow-poplar require somewhat higher pressures, 300 to 400 pounds per square inch, to be compressed to half the original thickness. Woods of higher specific gravity, such as birch and maple, cannot be compressed to half their original thickness under any pressure.

Under a pressure of 1,000 to 1,200 pounds per square inch most of the treated veneers compress to specific gravities, between 1.3 and 1.4. In

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[1]This mimeograph is one of a series of progress reports issued by the Forest Products Laboratory to aid the Nation's war program. Results here reported are often preliminary and may be revised as additional data become available.

doing so, woods like spruce, cottonwood, and aspen compress to about one-third of the original thickness. The denser, harder woods naturally are reduced less in thickness. With pressures of 1,000 to 1,200 pounds per square inch the treated woods are compressed almost to the maximum extent; that is, the void volume approaches zero. This is evident from the fact that the specific gravity of wood substance is about 1.46 and that of the resin about 1.28. Dry, untreated wood will, in general, require pressures of 2,000 to 5,000 pounds per square inch to be compressed to specific gravities of 1.3 to 1.4.

The increased compressibility of veneer treated by the Forest Products Laboratory method not only simplifies the manufacture of compreg, but it also makes possible the simultaneous compression of resin-treated plies and their assembly with either untreated veneer, or resin-treated veneer in which the resin has been precured by the application of heat alone, without compression. For example, resin-treated but uncured face plies of spruce can be compressed to about half their original thickness and simultaneously assembled to a dry, untreated spruce core at 250 pounds pressure per square inch with a resultant compression of the core of only 5 to 10 percent. If the core plies were similarly treated but the resin was set within their structure by the application of heat prior to assembly with the treated faces, the core would hardly compress at all under 250 pounds per square inch pressure. If the core was of untreated poplar, it would also be practically uncompressed under this pressure. If the spruce has a dry weight-dry volume specific gravity of 0.4, the poplar of 0.5, and the resin treatment increases the specific gravity of the wood by 18 percent (30 percent increase in weight and 12 percent increase in volume), then the specific gravity of the core in the three cases will, after assembly, vary from about 0.42 to 0.52 and the specific gravity of the faces will be about 1.0. It is thus possible to cause a variation in the specific gravity of the product of about twofold between the compressed and the uncompressed plies. The product can be made with the higher specific gravity plies either on the surface or in the interior, as desired. The only restriction is that the structure be balanced to avoid warping when the treated compressed plies are combined with untreated plies.

Besides the possibility of varying the specific gravity of the product in the thickness direction, it is possible to vary the specific gravity in the length direction by pressing a wedge-shaped pile of plies. Figure 1 shows one of a number of possible ways of laying up treated veneer to obtain specimens with varying specific gravity from one end to the other, together with the finished product. When pressing such unsymmetrically shaped piles of plies, the pressure is concentrated almost entirely at the heavy end. To avoid damage to the press because of the uneven loading, several specimens should be pressed at once with the heavy ends symmetrically arranged over the platen area. Specific gravities ranging from that of the uncompressed treated wood to about 1.4 can be obtained.

Gluing and Pressing

Bonding Glues

When resin-treated veneer is highly compressed in making parallel-laminated compreg, it is not necessary to use a bonding glue between the plies, provided the resin content exceeds 30 percent on the basis of the dry weight of the untreated wood[2]. When the resin content is below 30 percent, and when the veneer is cross banded or only partially compressed, an additional bonding agent should be used to obtain optimum shearing strengths. Hot-press spreading phenolic glue seems to be most satisfactory for this purpose. Slightly less than normal spread is sufficient.

Compreg panels can be satisfactorily glued to each other or to ordinary wood only after removing the surface glaze by sanding or machining. If the panels are thick it is important to machine the surfaces very flat to avoid locally thick glue lines.

Gluing can be done satisfactorily with a number of glues. Alkaline catalyzed phenolic glues that set below the boiling point of water appear most satisfactory and have been most extensively used[3].

Most Favorable Moisture Content

Experience has shown that it is desirable, especially when making thick specimens of highly compressed resin-treated wood, to dry the treated plies under nonpolymerizing conditions (see mimeograph 1380) to as low a moisture content as is practical, that is, about 2 percent moisture content. When hot-press glues are used, it is further desirable to redry the plies that have been coated with glue for about an hour at 160 to 170° F. prior to assembly of the plies. This procedure, it has been shown, practically eliminates end checking of thick pressed products, which may be very serious when the moisture content of the veneer is appreciable.

When resin-treated faces are being compressed and assembled with a dry untreated core or treated precured core in a single operation, it does not seem to be necessary to have the faces at so low a moisture content as 2 percent to avoid checking. In fact, it is undesirable to have them so dry if loss in differential compression between the faces and core is to be avoided. The moisture content of the faces at the time of assembly can, however, be too high, resulting in washboarding of the surface or face crazing when the product is taken hot from the press. The best compromise

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[2]See Forest Products Laboratory Mimeo. No. 1384, "Comparison of Commercial Water-soluble Phenol-formaldehyde Resinoids for Wood Impregnation," by Horace K. Burr, Assistant Chemist and Alfred J. Stamm, Principal Chemist.

[3]See Forest Products Laboratory Mimeo. No. 1346, "Gluing of Thin Compreg," by Herbert W. Eickner.

moisture content for the face plies prior to pressing has not been definitely determined as yet for the various species. A moisture content of 6 percent, however, seems to be satisfactory for at least some species, such as cottonwood, aspen, and yellow-poplar.

Temperature and Time of Pressing

Experience has shown that the higher the temperature of pressing, the greater will be the tendency to check. This is due to embrittlement of the treating resin. The best results have been obtained by pressing at 285 to 300° F.

When heating from the press platens, the time of heating will naturally depend upon the thickness of plies between the platens. If all the heat came from the platens the time for pressing would vary as the square of the thickness. In the case of the resin-forming mixes used, there is an appreciable amount of exothermic heat resulting from the reaction within the wood structure. As a result of this, the time required for setting the resin in thick specimens is somewhat reduced because of the fact that the internal temperature is built up more rapidly than by conduction alone. Cases have, in fact, been recorded in which the center temperature, as indicated by a thermocouple inserted at the center of thick assemblies (2-1/2 inches in the compressed condition) of resin-treated plies, rose 80° F. above the platen temperature of 310° F. and actually caused a slight charring. In making compreg blocks six inches thick, which were heated by high frequency to temperatures above 250° F., the temperature rose sufficiently because of the exothermic reaction to cause charring at the center of the block. This is due to the fact that heat was evolved from the reaction at the center of the wood more rapidly than it could be dissipated by conduction. In making 2-1/2 inch thick compreg when the platens were held at 285° F., the exothermic reaction was sufficiently slow that the generated heat could be conducted away as rapidly as it was generated, thus avoiding the undesirable building up of heat at the center. This is further reason for avoiding temperatures appreciably above 285° F.

Because of the effect of the thickness of the material pressed upon the pressing time when heating from the platens, the pressing time is preferably expressed as the time that the center of the wood should be held at the desired temperature. This can be estimated from the curing temperature-curing time-swelling curves of figure 2 for 17 parallel laminated plies of 1/16-inch birch veneer. These had been treated with enough Bakelite Resinoid XR5995 to give a potential resin content of 30 percent of the weight of the dry untreated wood, then dried at 170° F. for 5 hours at a relative humidity of 45 percent giving a moisture content of about 6 percent, and pressed at 1,000 pounds per square inch. In each case it took from 10 to 15 minutes to attain the desired temperature at the center and about 5 minutes to cool the panels to 200° F. at the center subsequent to curing. The cooling was necessary to prevent immediate springback of panels pressed under incomplete curing conditions. It further gives improved surfaces on all panels. The curves of figure 2 show, from the large swelling and springback occurring upon immersion in water, that the resin was not cured

in any of the panels at 235° F. At 260° F. the resin is partially cured only under the longest curing time of 45 minutes. At 285° F. it is completely cured in about 20 minutes and at 300° F. in about 10 minutes.

With the use of electrostatic heating equipment, the time required to bring the wood to the polmerization temperature should be markedly reduced. No data are as yet available on curing times by this method.

It has been found desirable to apply heat when possible before exerting pressures great enough to compress the wood, as less stresses and rupture of the structure seem to result under these conditions due to plasticization of the wood. This procedure, however, cannot be followed in making thick, compressed material heated only by the platens. In such a case it is necessary to apply compressing pressures before the center of the wood is plastic, to avoid setting the resin in the outer plies before they are compressed. This difficulty can be largely avoided by preheating the plies or by using high frequency heating.

Thick material should be cooled in the press until the center of the wood is down to about 200 to 220° F. before releasing the pressure, especially when the moisture content of the wood is appreciably above 2 percent. This procedure is necessary to avoid the formation of steam blisters, crazing of the surface, and washboarding of the surface in woods with contrasty grain. Surface crazing can, however, be avoided with most of the species tested by using very dry treated veneer. It is advisable that the cooling step be omitted only when making relatively thin panels, using quite dry treated veneer of uniform textured woods, such as cottonwood, aspen, and yellow-poplar or when the pressed surface is to be machined from thick blocks of compreg made at moisture contents below 2 percent.

Properties

Moisture Absorption and Swelling

Compreg is far more resistant to moisture absorption from the liquid phase than the corresponding uncompressed resin-treated wood. This is due to the relative lack of mechanical voids and capillary structure in the compressed material. The final equilibrium adsorption of water from the vapor phase, however, is practically unaffected by compression, although the rate of adsorption is considerably less for the compressed material. Similarly, the rate of swelling of compreg is considerably less than that for impreg, but the former will swell to a greater degree, due to the fact that the amount of fiber substance per unit dimension is increased.

Compreg made with less stabilizing resins will not only absorb considerably more water and swell to a considerably greater extent but it will permanently recover from its compressed state to an appreciable degree when swollen.

Small blocks of spruce compreg 7/8-inch long in the fiber direction swelled only 3.6 percent in thickness after 50 days' immersion in water and after 1 year they swelled but 5.4 percent. Specimens of spruce compreg 1 by 10 by 10 centimeters in size absorbed 0.5 percent of moisture by weight in 1 day, 1.2 percent in 4 days, and 1.8 percent in 7 days of complete immersion. The German specifications allow a weight increase for laminated, resin-treated, compressed wood prepared by their methods of 5.0, 7.0, and 8.0 percent, using specimens of the same size, and for the same lengths of time. A group of highly compressed specimens of birch compreg 7/8-inch long in the fiber direction that were cured under different conditions absorbed, on the average, 5.0 percent of water and swelled about 5 percent in thickness after 30 days' immersion in water (figure 2). Similar specimens adsorbed about 4 percent of water vapor and swelled about 3.5 percent in thickness when subjected to a relative humidity of 97 percent for 44 days. Similar specimens of maple compreg 7/8-inch long in the fiber direction swelled 0.7 percent after 4 days' immersion in water, 1.5 percent after 11 days, 3.7 percent after 30 days, and 5.4 percent after 60 days.

Army Air Forces specification No. 15065 of June 10, 1942 for compreg allowed a maximum water absorption, after 24 hours' water immersion, of 6 percent by a specimen 3 inches by 1 inch by 3/8 inch (1 inch in the fiber direction). The new specification, No. 15065-A, March 15, 1944, allows but 2.5 percent water absorption. Compreg made from resin-treated veneer according to the Forest Products Laboratory procedure (Mimeo. 1380) will absorb less than 1 percent moisture under these conditions.

A few tests indicate that compreg serves as even a better moisture barrier than the uncompressed resin-treated wood (see mimeo 1380). The moisture transfusion through a panel under a relative humidity gradient is, for most purposes, negligible.

Surface Finish

Compreg has a lustrous varnish-like finish when it is compressed between highly polished platens. The degree of luster diminishes with a decrease in the polish of the mold, a decrease in the compression of the wood, and an increase in the amount of precuring of the plies prior to pressing. Cut surfaces of the compressed material in which the resin within the cell-wall structure was cured at the time of pressing can be sanded and buffed to give fully as lustrous a finish as can be obtained with the platens. The wood is finished throughout the structure. Sanding and buffing to give a smooth surface merely bring out the finish. Articles manufactured from resin-treated, compressed wood can thus be restored to their original finish when scratched or marred by merely sanding and buffing.

Compreg made according to the Forest Products Laboratory method between polished metal platens has a high surface hardness and finish as shown by tests made with a Sword surface hardness tester, which measures a combination of smoothness and hardness. The instrument, which is calibrated to give an empirical reading of 100 for plate glass, gives values ranging from

65 to 90 for different resin-treated, compressed wood specimens with different resin contents made under different degrees of compression. Ordinary smooth spruce gave a value of 6. The latter with a good varnish finish gave a value of 18.

Only a few tests have thus far been made on painting compreg with a yellow lacquer and a yellow enamel used by the Army for painting insignia on metal airplanes. One coat was sprayed on half of the surface of panels with resin-treated, compressed faces of spruce and on untreated, uncompressed spruce controls. The one coat gave a smooth finish on the treated panels, but on the controls showed an obvious need for building up the finish. Southern exposure out-of-door weathering tests after three years showed no deleterious weathering of the film in any case. Some face checking of the untreated controls occurred through the paint film, starting largely at the exposed unpainted parts of the panels. As far as the tests go, it appears that this type of lacquer or enamel will stand up satisfactorily on resin-treated, compressed wood.

Strength Properties

The strength properties of compreg are, in general, appreciably greater than those of normal untreated wood. The specific strength properties (strength per unit specific gravity), are, however, in all cases but the compressive strength, less for compreg than for normal wood. The increased strength is primarily due to the compression of the wood. The resin seems to be effective only in increasing the compressive-strength properties and the shear. It further causes an appreciable decrease in the toughness.

Table 1 gives the strength values obtained on a panel consisting of 16 parallel laminations of 1/16-inch rotary cut spruce veneer containing about 35 percent of resin on the basis of the weight of the dry untreated wood that had been compressed to 0.35 of the original thickness and an average specific gravity of 1.32. No glue was used between the plies. The data show that laminated, resin-treated, compressed wood has very high strength properties. Because of the limited number of tests, these values can be considered only as approximate properties.

Inasmuch as the data on properties are related to test methods, a brief description of the tests is pertinent. Because of the small size of the samples, and their thinness, the standard test methods are not applicable without some modification.

Tension parallel to grain.--The specimen was approximately 14 inches long with an end cross section 1 inch by approximately 0.35 inch (the thickness of the panel) and a central cross section 3/8 by 3/16 inch. The center 2-1/2 inches of the length of the specimen was of constant cross section and the transition from the central cross section to the end cross section was effected with a curve of 30-inch radius. A constant rate of motion of the movable head of the testing machine of 0.025 inch per minute was used, and strain measurements over a 1-inch gage length were taken

during the early portion of the test. This specimen is substandard, in that the tension test recently developed calls for a specimen 26-1/2 inches long to provide a more favorable filler radius.

Compression parallel to grain.--A specimen 1-3/8 inches long (4 times least dimension) by 1 inch wide by approximately 0.35 inch (the thickness of the panel) was used. A constant rate of movement of the movable head of the testing machine of 0.004 inch per minute was used, and strain measurements over a 1/2-inch gage length were taken during the early portion of the test.

Static bending.--The specimen used was 2 inches wide and sufficiently long to provide a ratio of span to depth of 14. Center loading was used, with a rate of descent of the movable head of 0.018 inch per minute.

Shear parallel to grain.--The specimen used was 2-1/2 inches long by 2 inches wide by the thickness of the panel, with a notch 1/2 by 3/4 inch in one corner. The rate of descent of the movable head was 0.015 inch per minute. The specimen was an adaptation of the Forest Products Laboratory standard shear test specimen, differing from the standard only in that the thickness or width was approximately 0.35 inch instead of 2 inches.

The Johnson shear tests[4] were made on specimens 1 inch wide and 1/2 inch deep cut from another specimen 1 inch thick.

In conjunction with curing tests on resin-treated, parallel-laminated, compressed birch bonded with phenolic film and made under the conditions given on page 4, measurements were made of the modulus of rupture and the modulus of elasticity in static bending, and the shear parallel to the grain and across the plies, by the Forest Products Laboratory method. For these tests, 45 different specimens cured under different conditions were used. The average, the maximum, and the minimum values for the modulus of rupture were 40,300, 47,000, and 36,500 pounds per square inch. The corresponding modulus of elasticity values were 3.64, 3.92, and 3.25 million pounds per square inch, and the comparable maximum shearing strength values were 4,000, 4,500, and 3,700 pounds per square inch.

Shear values are highly dependent upon the method. Values taken from different sources hence should not be compared unless the method and the size of the specimens are identical. For example, the standard Forest Products Laboratory shear-test method for testing the joints of glue blocks gave about double the values on compreg that were obtained by the Laboratory's shear-test method for normal wood when shearing in the plane of the plies.

The shear strength of compreg parallel to the grain is considerably greater in the direction in which the surface of failure is parallel to the direction of compression than it is when the surface of failure is at right angles to the direction of compression, even when the bond between the plies is sufficiently strong to give 100 percent wood failure. It has been shown from tests on solid blocks of wood compressed in either the radial or

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[4]Described in Johnson's Materials of Construction, by Withey and Aston, 7th ed., John Wiley & Sons, 1930, p. 61.

tangential structural directions of the wood that the structural direction of the wood plays only a minor part in the difference. The difference seems to be due primarily to variations in the structure in the direction of compression and at right angles to the direction caused by the compression. The average shear strength parallel to the grain and in the direction in which the compression was applied for 24 plies of laminated, resin-treated, compressed sweetgum specimens that were bonded with phenolic film, was as determined by the Forest Products Laboratory method, 3,200 pounds per square inch. The corresponding value for the shear at right angles to the direction of compression was 1,200 pounds per square inch. Similar averages for six specimens of cottonwood were 2,600 pounds per square inch in the direction of compression and 1,500 pounds at right angles to the direction of compression. Only the shear strength, in the direction in which the plane of rupture is parallel to the direction of compression, is appreciably increased over that for the normal wood.

The shear strength in the plane of the plies is highly dependent upon the nature of the bonding material, especially when the dense, stronger woods like birch that cannot be greatly compressed are used. In the case of parallel laminated highly compressible woods like spruce, 100 percent wood failure is obtained with the treating resin exuding from the plies serves entirely as the bonding medium. In the case of sweetgum and birch, glue failure sometimes occurs, indicating that the bond may not be as strong as the wood. When phenolic film is used as the bonding medium for resin-treated, parallel-laminated sweetgum, 100 percent wood failure is obtained in the shear tests. In the case of birch the failure is largely glue failure, indicating that the wood is stronger than the paper lamina containing the resin glue. When hot-press phenolic glues of the spreading type are used, 100 percent wood failure is obtained even with birch. For example, birch compreg that was bonded with phenolic film gave shear strength values in the plane of the plies in a series of 45 tests of only 900 to 1,600 pounds per square inch. In all cases glue failure predominated. When a hot-press phenolic spreading glue was used, 10 specimens gave shear strengths averaging 2,000 pounds per square inch, and complete wood failure resulted.

The modulus of rupture in bonding and the modulus of elasticity are practically unaffected by curing conditions above a minimum threshold value[5]. The toughness, however, is greatly affected by the condition of cure, overcure causing a decrease in toughness[6].

More extensive strength data for birch compreg are given in the forthcoming ANC-18 bulletin, "Design of Wood Aircraft Structures" to appear in print soon.

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[5]See Forest Products Laboratory Mimeo. No. 1383, "Effect of Resin Treatment and Compression Upon the Properties of wood," by R. M. Seborg and Alfred J. Stamm.

[6]See Forest Products Laboratory Mimeo. No. 1386, "Influence of Manufacturing Variables on the Impact Resistance of Resin-treated Wood," by M. A. Millett, R. M. Seborg, and A. J. Stamm.

Fabrication and Molding

It is more difficult to cut and machine compreg than normal wood, but less difficult than metals. Special hardened saws and tools should be used; lower tool speeds than for normal wood are desirable.

Because compreg is more difficult to machine than treated uncompressed and uncured wood, the Forest Products Laboratory developed a method for molding precarved blanks rather than carving the final compreg blanks. The process is now in use for molding "club" motor test propellers and aerial masts. Resin-treated veneer is glued up into blanks with a phenolic glue, such as Resinous Products PR14, or Bakelite cold-setting resin XC3931 with less than normal amount of catalyst XK2997, under conditions such that the bonding glue sets only partially and the treating resin is unaffected (temperatures below the boiling point of water). The blanks are then carved to the desired width and shape but with a thickness 1-1/2 to 2-1/2 times that of the finished product. The carved blanks are then heated and compressed in a split mold to the final desired specific gravity. A slight flash that can be readily machined off normally occurs at the parting line.

Some experimental work has been done in cooperation with a Madison, Wisconsin, company in molding airplane landing wheels. In this case, the plies have been arranged with the grain of each ply at 45 degrees to that of the next, rather than employing parallel laminations as is done with propeller blanks. Blanks were glued up with a cold-setting phenolic glue with an insufficient amount of catalyst present to set the resin completely at room temperature, just as were the blanks for the molded airplane propellers. These were turned to shape, but with a greater thickness than that of the finished product, and then pressed in a mold, consisting of a series of rings and stops, to the final dimensions. Another possible procedure would be to punch discs of the proper sizes from the treated veneer, apply a hot-press glue, and assemble in the mold followed by pressing.

Uses

Compreg is finding its most extensive war use in airplane propellers, motor testing "club" propellers, aerial masts, bearing plates, and various connectors that can be improved by the use of a material with greater tensile, compressive, and shear strengths than the normal wood; also for various tooling jigs. It likewise appears suitable for pulleys, silent gears, and water-lubricated bearings.

Panels with resin-treated compressed faces on an untreated or treated and precured uncompressed core show promise for skin coverings of airplanes, small boats, pontoons, and similar products. Preliminary tests show that thin 3-ply plywood made from 1/45-inch birch veneer can be steam bent almost as easily as untreated plywood when the outer face is resin treated and compressed. When both faces are treated and the outer face is compressed and

the inner precured, it is more difficult to steam bend the material because of the increased compressive strength of the inner ply, but it can be accomplished with a radius of curvature of about 2 inches. Such panels show promise for postwar use in house paneling, siding, and flooring.

Cost

The cost of resin-treated, compressed wood will be primarily dependent upon the cost of the treating resin, the veneer, and the treating process, all of which have been discussed in mimeograph No. 1380. The cost per unit volume will be increased primarily because both the wood and the resin are made to occupy a smaller volume under compression. The cost of compressing and assembling in the form of flat panels will be but slightly more than the cost of assembly of the resin-treated, uncompressed material. The cost of production of resin-treated, compressed wood per pound will vary from about 15 to 30 cents, depending upon the species of wood used and the thickness of the panels.

Availability

Compreg is now manufactured by the following companies:

Camfield Manufacturing Co., Grand Haven, Mich.
Farley-Loetscher Manufacturing Co., Dubuque, Iowa.
Formica Insulation Co., Cincinnati, Ohio.
Panelyte Division, St. Regis Paper Co., Trenton, N. J.
Parkwood Corp., Wakefield, Mass.
Pluswood, Inc., Oshkosh, Wis.
The Rudolph Wurlitzer Co., DeKalb, Ill.

The material is at present available only for war use.

References

1. The Antishrink Treatment of Wood with Synthetic Resin-forming Materials and Its Application in Making Superior Plywood, by A. J. Stamm and R. M. Seborg. Forest Products Laboratory Mimeograph R1213.

2. Resin-treated, Laminated, Compressed Wood, by A. J. Stamm and R. M. Seborg. Forest Products Laboratory Mimeograph R1268.

3. The Compression of Wood, by R. M. Seborg and A. J. Stamm. Forest Products Laboratory Mimeograph R1258.

4. Effect of Resin Treatment and Compression upon the Properties of Wood, by R. M. Seborg and A. J. Stamm. Report given at the American Society of Mechanical Engineers meeting in Louisville, Kentucky, October, 1941, Forest Products Laboratory Mimeograph 1383.

5. Forest Products Laboratory Resin-treated Wood (Impreg), by A. J. Stamm and R. M. Seborg. Forest Products Laboratory Mimeograph 1380.

Table 1.--Strength values for resin-treated, parallel-laminated spruce compressed to a specific gravity of 1.32

	Number of tests	F.P.L. Compreg.	German specifications[1]
		Average Lb./sq.in.	
Tension parallel to the grain:			
Maximum tensile strength.......	7	42,500	28,500
Modulus of elasticity..........	1	4,700,000	---
Compression parallel to grain:			
Maximum crushing strength......	8	23,400	18,500
Modulus of elasticity..........	8	5,000,000	---
Static bending:			
Modulus of rupture......	4	43,400	35,500
Modulus of elasticity..........	4	4,400,000	2,700,000
Shearing parallel to the grain -- Maximum shearing strength perpendicular to plies:			
Modified F.P.L. method.......	4	3,000	
Johnson single shear method..	1	5,000	
Johnson double shear method..	1	6,000	

[1] Strength values taken from the German specifications for artificial resin-treated compressed wood (Kunststoffe 30:58-62 [1940]) are given here for comparison.

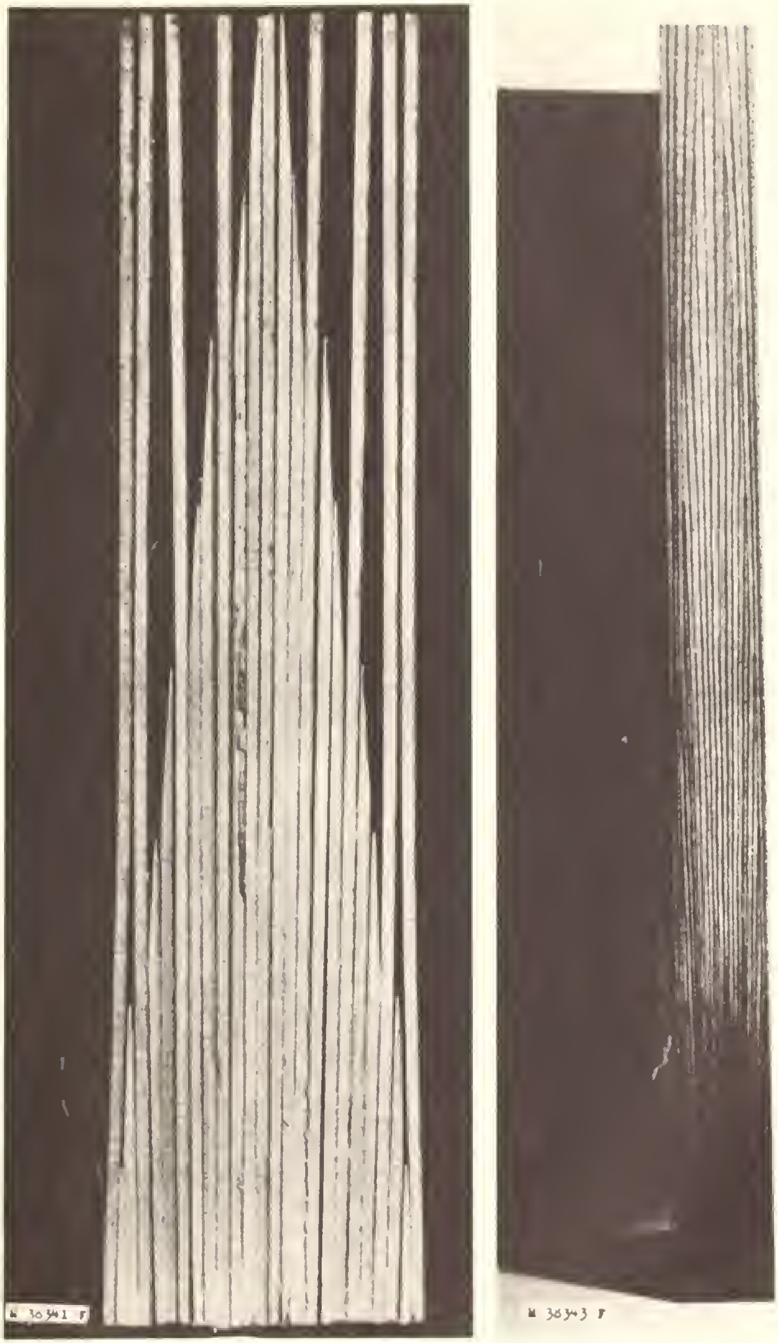

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Fig. 1. Means of laying up veneer to obtain product with varying specific gravity from one end to the other.

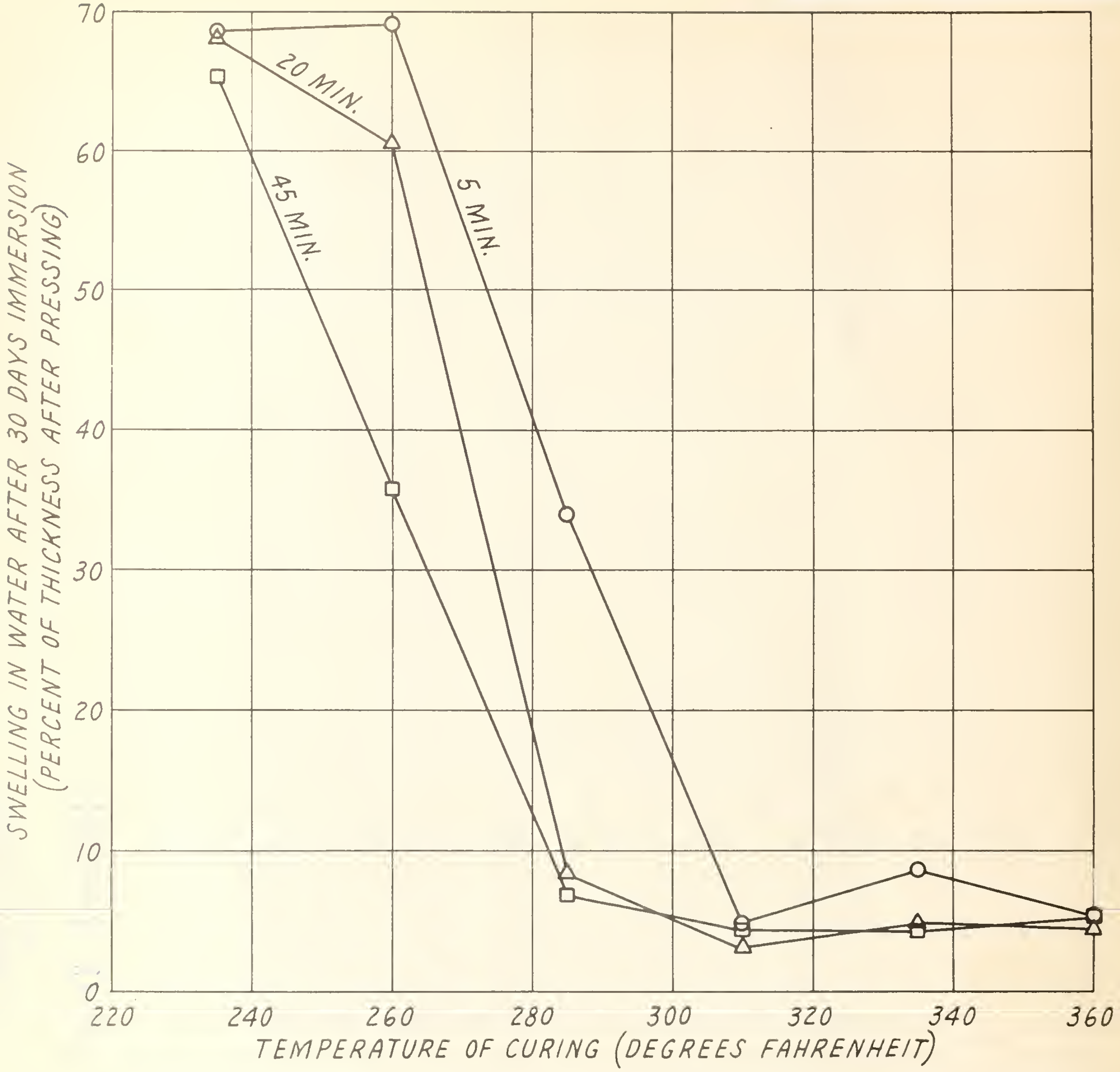

Fig. 2. Relation of the temperature at three periods of cure to the combined swelling and recovery from compression of laminated, resin-treated, compressed birch in the direction of compression when immersed in water. Times are in terms of the period that the center of the wood is held at the designated temperature.

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